NOTES ON THE OCCURRENCE OF GLENDONITES AND GLACIAL ERRATICS IN UPPER MARINE BEDS AT ULLADULLA, N.S.W.

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(Plates xiv-xv; and two Text-figures.)

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Introduction.

The following notes have been prepared with the object of recording several interesting occurrences in Upper Marine Permo-Carboniferous rocks near Ulladulla, on the South Coast of New South Wales.

The features described occur on the sea-cut rock platforms developed along several miles of the coast; in common with similar features along the East-Australian coast, these platforms are exposed at low tide but are covered at high tide. The accompanying sketch map (Plate xiv) gives an indication of the geological structures on these platforms only.

Although faceted erratic pebbles have been known to occur in the sea-cut rock platforms near Ulladulla, as far as can be ascertained, no record has been made of the occurrence.

Previous Literature.

Evidence of glacial conditions in the Upper Marine Beds, near the mouth of the Shoalhaven River, was recorded by E. O. Thiele (*Proc. Roy. Soc. Vict.* xvi, Part 1, 1903, 57-59). No glendonites were mentioned, but it is now known that they occur at Crookhaven, near the mouth of the Shoalhaven River.

A complete bibliography of previous work on glendonites has been given by Professor David, Dr. Woolnough and Messrs. Taylor and Foxall (*Rec. Geol. Surv. N.S.W.* viii, 1905, 161-179), who definitely established the identity of "glendonite" as a pseudomorph after glauberite, and recorded four occurrences of Glendonites, all in Upper Marine Beds, three in the Hunter River District and one at Huskisson, Jervis Bay.

Later, Dr. A. B. Walkom (These Proceedings xxxviii, Part 1, 1913, 160) recorded all the known occurrences of Glendonite in Upper Marine (Permo-Carboniferous) Beds and described a new horizon in Lower Marine Beds at Harper's Hill in the Hunter River District.

It is considered that the glendonite beds about to be described are in a new locality, although not on a new horizon. Ulladulla is situated about 108 miles by sea from Sydney on the South Coast of New South Wales. The glendonites and erratics occur about 100 feet below the top of the Ulladulla Mudstones, which

underlie the Nowra Grits, and within 300-400 feet of the base of the Upper Marine Series in this area.

Ulladulla Mudstones.

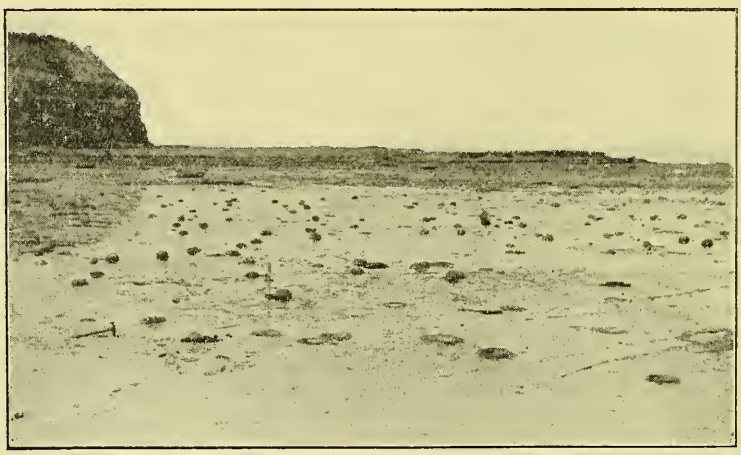
The Ulladulla Mudstones probably do not exceed a few hundred feet in thickness at Ulladulla; they thin out completely a few miles to the south, and probably thin out more rapidly to the west. The overlying Nowra Grits rest unconformably on folded Devonian Slates at Yackengarrah Creek, about eight miles northwest of Ulladulla, and no trace of the Mudstones was found between this spot and the coast.

The mudstones are exposed along the coast for several miles north and south of Ulladulla Harbour. They are generally level-bedded or have a slight dip (up to 7°) to the east of north, but many local variations occur. In some cases these variations are due to the intrusion of basalt dykes probably of Tertiary age. More intensive folding and contortion occur in fossiliferous calcareous mudstones at Warden Head and North Head of Ulladulla Harbour. These contortions seem to have been contemporaneous with the formation of the beds, as they do not affect those beds immediately higher in the series.

Evidently associated with the folding, although of later date, faulting parallel to the axes of folding is indicated by four small reverse faults, showing underthrusting from the west. The faults have an average dip of 15° to the east with a throw of six to ten feet and a heave of twenty to thirty feet.

It is suggested that the strengthening of the strata by this compression has been a factor in the formation of both Warden Head and North Head: Warden Head runs out for over a mile from the general trend of the coast.

The mudstones are grey in colour and show fine laminations. In some places they are more or less calcareous, and they merge upwards into sandy beds. Spheroidal concretions about eight inches in diameter, embedded or partly embedded in the mudstones, form a striking feature on the rock platform, on both



Text-fig. 1.—Rock platform at Warden Head, Ulladulla, showing concretions exposed at low tide.

the north and south sides of Warden Head, as indicated on the accompanying map. They seem to be composed of material similar to the rock in which they occur and in some cases were found to contain a fragment of foreign rock or fossil in the centre.

Glendonites.

Glendonites were found over the areas indicated on the map (Plate xiv), the principal area being on the rock platform exposed at low tide, to the north of Warden Light House. At low tide the width of the platform is from 80 to 100 yards and the length over 500 yards. The beds dip at about 10° towards the foot of the cliffs in a direction W.15°S., thus the strike of the beds is nearly parallel to the trend of the neighbouring sea cliffs. Glendonites are exposed over the length of the platform (Plate xv, and Text-fig. 1), the base of the lowest horizon being about 75 yards from the base of the cliffs. Three beds with abundant glendonites occur along this platform, separated by thin beds particularly rich in fossils: the two lower glendonite beds merge into one another further north.

The following vertical section has been estimated for the rocks outcropping on this part of the platform.

Feet.	
25	Mudstones with numerous small erratics and some fossils.
6	Mudstones containing Glendonites.
1	Argillaceous limestone with *Cleobis* and *Pecten*.
7	Fossiliferous mudstone with Glendonites.
4½	Ferruginous mudstone with numerous erratic pebbles and abundant fossils (*Strophalosia, Spirifer,* Crinoids, *Fenestella*, etc.)
4½	Lower Glendonite horizon.
10	Mudstones with numerous erratic pebbles.

Overlying this series is another bed, containing glendonites associated with *Zaphrentis* and *Strophalosia*. It outcrops both on the north and south sides of Warden Head and seems to be separated from the lower complex glendonite horizon by a vertical thickness of about 30 feet of mudstones with erratics, but exact correlation was impossible on account of the many slight variations in dip.

On the platform round North Head there is another glendonite horizon, underlying a bed especially rich in *Strophalosia*. The strike here is approximately north and south, but, as a wide dyke fissure occurs immediately to the east, running in a northerly direction, this variation in the direction of strike is probably quite local. In all other respects, this occurrence corresponds with that of the Upper Glendonite bed at Warden Head to the south.

The glendonites occur as clumps of a dozen or more individuals, grouped together and embedded in the mudstone. The diameter of a group varies from three to six inches. Only two or three single crystals, each about six inches in length and an inch in thickness, were seen among hundreds of groups. An average of three clumps to the square yard occurs over most of the areas exposed.

In several cases the glendonites enclosed or partly enclosed *Zaphrentis*, *Strophalosia* or other shell fragments, in exactly the same fashion as was observed at Huskisson by Professor David, indicating the growth of the original glauberite (after which the glendonites are pseudomorphous) in soft muds containing the remains of marine organisms. The glendonites also cut through the bedding planes of the shales.

Chemical.—A few of the glendonites appeared to be composed of material similar to that at Huskisson, an analysis of which is given in the paper previously

mentioned. These were tested qualitatively and proved to consist of dark carbonate of calcium, almost entirely soluble in cold, dilute hydrochloric acid. No trace of barium or sulphates was found.

Most of the glendonites, however, consist of carbonate of iron, which, for a time, withstands weathering better than the surrounding shales. After a time the substance of the glendonites is attacked more rapidly and dissolved out, leaving hollow moulds. Not only the glendonites, but also the numerous fossils occurring with them, are completely replaced by carbonate of iron over a considerable area of the rock platform.

Crystallographic.—Crystallographically, the glendonites seem to be similar to those already described. No simple crystals which were suitable for measuring were observed, the majority of specimens consisting of complex groupings of a number of individuals, many of which show striated faces similar to that figured by Dr. Walkom (THESE PROCEEDINGS xxxviii, 1913, 167).

Petrographical.—Under the microscope, a section of a glendonite composed of calcium carbonate consists of three different types of calcite; the first type is brown in colour and shows a fibrous radiating structure, the second type has a yellowish colour and occurs as irregular grains, whilst the third type is quite clear and colourless and appears to fill in the spaces left in the calcite of the first type. The yellowish colour is due to traces of iron.

This is exactly similar to the calcite of the Huskisson glendonites, described by Mr. G. W. Card in the paper on the Jervis Bay occurrence.

The Erratics.

Erratic boulders occur in the rock platforms and adjacent cliffs over almost the whole of the area mapped, and are found in the beds containing very abundant fossils, in the glendonite beds and also in the overlying mudstones which are relatively barren of fossils. In size, they vary from a fraction of an inch in diameter to blocks over six feet in length: the large erratics occur in the mudstones stratigraphically above the glendonite beds. The erratics are mostly subangular, but many are well faceted. No undoubted striations were found on them.

They consist chiefly of granite, granite-gneiss, fine-grained schist, green slaty phyllite, black slates, quartz-porphyry, tuffs, quartzite, and milky quartz. The main types at Huskisson were described as "granite, mica-schist, aplite and quartz-porphyry."

The largest block was found embedded in the platform south of Coller's Beach (Plate xv). It measures seven feet by four feet six inches and is exposed to a depth of three feet. The longer axis in this case is running north and south. From its appearance it seems likely that less than half of it is exposed, so that its weight is probably of the order of 14 tons. It consists of grey granite-gneiss, medium to fine-grained, showing a distinct banding. In the hand-specimen, it appears to consist of quartz, white felspar and mica. The microscope reveals that the quartz "grains" have been shattered to a fine mosaic, accentuating the gneissic strucure; the felspar consists of orthoclase, microcline and plagioclase as irregular medium-sized grains, and the muscovite and biotite occur as more or less parallel wisps scattered through the rock. The biotite is partly decomposed but shows bending as evidence of strain. Assistant-Professor W. R. Browne has drawn my attention to the fact that a rock of this type has been described by Mahony and Taylor (Report on a Geological Reconnaissance of the Federal Territory, 1913, p.

54). It outcrops to the south of Canberra, on the western side of the Murrumbidgee River. A microsection of a specimen from Tharwa, in this region, shows a remarkable similarity in structure and mineral constitution to the erratic at Ulladulla, which is situated 70 miles due east of Tharwa.

This is perhaps the only rock type having any distinctive character, which might give an indication of the direction in which the ice moved its load of erratics.

Quartz porphyries and tuff are recorded as occurring in a belt to the east of the gneissose granites of the Murrumbidgee and small erratics of a quartz porphyry, with quartz and decomposing felspars in a devitrified groundmass, are very abundant in the mudstones near Ulladulla.

Pale green slaty phyllite exactly similar to rocks of Devonian age occurring to the west and south are found as erratics associated with quartzites and fragments of vein-quartz.

Several large erratics and numerous small pebbles are composed of a more or less weathered granite consisting of quartz, orthoclase and biotite. A somewhat finer-grained biotite-granite is known to occur about twelve miles away, but, as is the case with most of the other erratics, the type is rather common for definite correlation.

The longer axes of the large erratics point either from the west or from the south-west.

Summary and Conclusions.

The evidence, although not conclusive, seems to indicate that the great masses of ice, which were floating about in the sea during the formation of these Upper Marine beds, and continually dropping their loads into the soft muds forming on the sea floor, came from land situated to the west and south-west of the Ulladulla district.

The immediate effect of the cold conditions was to kill off large numbers of the organisms existing in the sea, resulting in the development of beds now exceptionally rich in marine fossils.

It is in the mudstones closely associated with these fossil beds that the glendonites occur, and they have not been found in the overlying mudstones, which do not contain abundant fossils, although continued cold conditions are indicated by the presence of numerous erratics. This may have some bearing on the conditions of the formation of the glendonites. Under inference number (x) of the summary of the paper by Professor David, Dr. Woolnough and Messrs. Taylor and Foxall, it is stated that "Possibly, suitable sulphate-forming bacteria may have existed in the black muds of the matrix." From the evidence available it seems possible that the sulphur necessary for the formation of the original glauberite, may have been derived from the decomposition of the soft parts of the abundant marine organisms, with or without the aid of bacterial action.

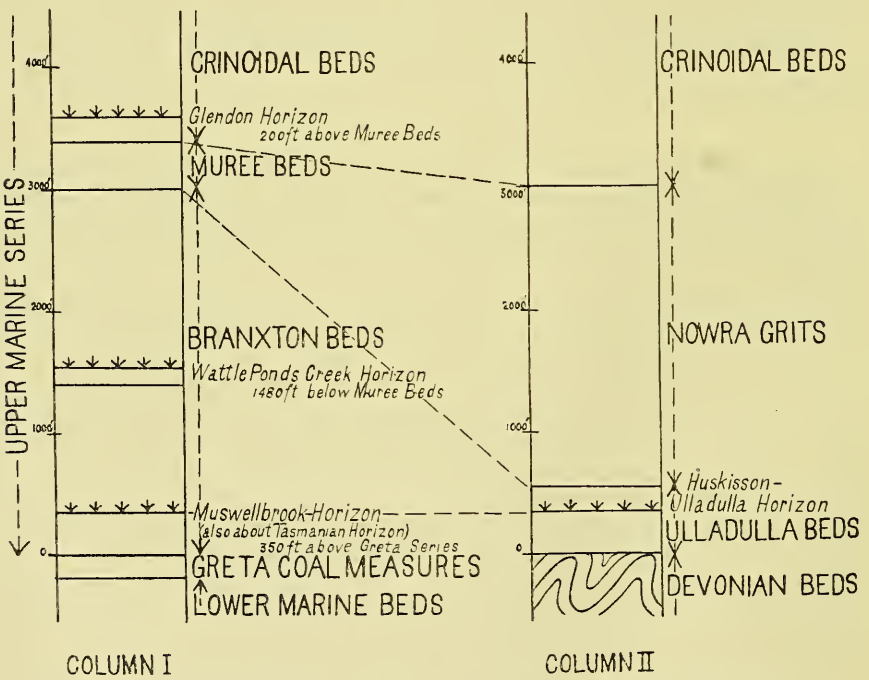
It is noteworthy that where glendonites occur in other localities, abundant fossils are frequently associated with them. This is true of the Lower Marine occurrence near Lochinvar, and the Upper Marine glendonites of the Hunter River District at Singleton.

It also holds good at Wollongong, Gerringong, Crookhaven and Huskisson as well as at Ulladulla. The fossils which are usually present consist of brachiopods, together with lamellibranchs, simple corals, crinoids and polyzoans. It is not known which, if any, of the microscopic forms, like Foraminifera, are present.

No information could be obtained as to the amount of sulphur that is likely to be available from this source, but the constant association of glendonites and marine fossils suggests some such causal connection.

The stratigraphical position of these glendonite beds, about 100-200 feet below the Nowra Grits, suggests that they may be correlated directly with the Huskisson beds to the north, and Mr. W. S. Dun, in conversation on the subject, said he considered from palaeontological evidence, that these horizons are identical.

If the Nowra Grits are the equivalents of the Muree Beds of the Hunter River District, as first suggested by Professor David (*Ann. Rept. Dept. Mines, N.S.W.*, 1890, 250), then the Huskisson-Ulladulla horizon may certainly be represented as occurring 100-200 feet below these beds: but they are also within 300-400 feet of the base of the Upper Marine beds as developed in this area: thus it is possible that this horizon may be equivalent to the Muswellbrook and Tasmanian horizons, 350 feet above the Greta Series rather than forming a separate one higher in the Upper Marine Series, as indicated in the vertical section of the Permo-Carboniferous System given by Dr. A. B. Walkom, which is partly reproduced



Text-fig. 2.—Vertical sections of parts of the Permo-Carboniferous System, showing suggested correlation of Glendonite horizons in the northern and southern coalfields.

in column i of text-figure 2. Column ii shows the equivalent stratigraphical succession in the South Coast District. Professor David, in his discussion of the Huskisson Beds, has correlated them with "the *Zaphrentis* horizon of the Branxton Beds (of the Hunter Coal-field) on the S.E. side of Black Creek. The latter

horizon is about 800 feet below the base of the Muree rock, and about 2,300 feet above the horizon of the Greta Coal Measures."

The position of the Wattle Ponds Creek horizon has been measured only with reference to the Muree rock, and may therefore also be equivalent to the Muswellbrook and Huskisson horizons.

The difficulty of correlating definite horizons is due to the unequal development of the marine beds in the Southern and Northern Coalfields.

The evidence in the Ulladulla District tends to confirm the inferences deduced in the paper by Professor David, Dr. Woolnough and others, with the exception of number (vi), which states that "The horizons of the glendonites being not far below, in some cases close to, the top of the highest beds of a Marine Series, where they are about to give place to fresh-water beds . . . ."

The Ulladulla Mudstones, in which the glendonites occur, are themselves the lowest beds of a marine series; the overlying level-bedded Nowra Grits are of the order of two thousand feet in thickness, and contain marine fossils at intervals right to the top of the series at Little Forest, a few miles north-west of Ulladulla at a height of 1,800 feet above sea-level, and almost that height stratigraphically over the glendonite beds.

In conclusion, the writer wishes to thank Assistant-Professor W. R. Browne for his advice on the preparation of this note.

EXPLANATION OF PLATES XIV-XV.

Plate xiv.

Sketch-map of the coast near Ulladulla, N.S.W., showing Glendonite horizons.

Plate xv.

1. Group of Glendonites from Warden Head near Ulladulla. Photo: H. G. Gooch.
2. Glendonites *in situ* on the rock platform at Warden Head, Ulladulla.
3. Large erratic of granite-gneiss embedded in rock platform at south end of Coller's Beach, near Ulladulla.